X-ray magneto-optic Kerr effect (XMOKE) studies of spring magnet heterostructures

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INTRODUCTION

With increasing interest in reflectance and scattering measurements of resonant magnetic signals rather than electron-yield MCD signals,[1] it is important to understand the complexity and value of simultaneous phase and intensity effects in the scattered photon field. With this goal, we used the complex magnetization reversal of Sm-Co/Fe exchange spring films to test the sensitivity of different resonant XMOKE measurements to changes in longitudinal and transverse moments within the soft Fe layer, and to changes in these moments in depth within the Fe layer.[2] Exchange-spring films are heteromagnetic materials of interest to increase the stored energy product beyond values obtainable from single-phase magnets. Such structures utilize strong interfacial exchange between hard and soft magnetic layers to yield 3-D spiral magnetization structures on reversal. These magnetization structures are ideal systems to test the sensitivity of different XMOKE techniques involving intensity and polarization effects using either incident linear or elliptical (near-circular) polarization.

An endstation designed to measure both phase and intensity XMOKE signals was positioned in the beam from the elliptically polarizing undulator (EPU beamline 4.0) for this study. Two different detectors were used as shown schematically in Fig. 1. The downstream detector is a tunable linear polarizer to measure polarization and polarization changes associated with Kerr effects. The upstream detector measures the Kerr intensity, which is simply the total reflected intensity. The layered sample studied here was grown on MgO (110) to have nominal structure MgO/Cr(20 nm)/Sm-Co(20 nm)/Fe(20 nm)/Cr(5 nm), where the quasi-epitaxial Sm-Co layer is the hard magnetic layer and Fe the soft layer. The sample has uniaxial in-plane anisotropy, and measurements were made in a longitudinal field along the easy axis. Here we report on the behavior of the soft Fe layer only as determined by tuning near the Fe 2*p* resonances.

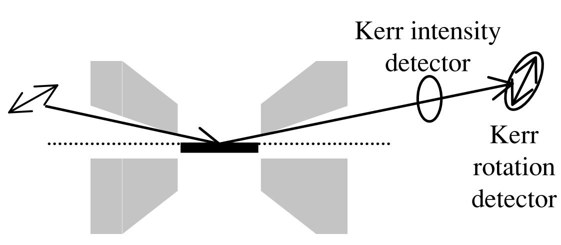

Figure 1. Experimental geometry showing linearly polarized beam reflected off sample in poles of electromagnet. One of two downstream detectors measures Kerr intensity or rotation.

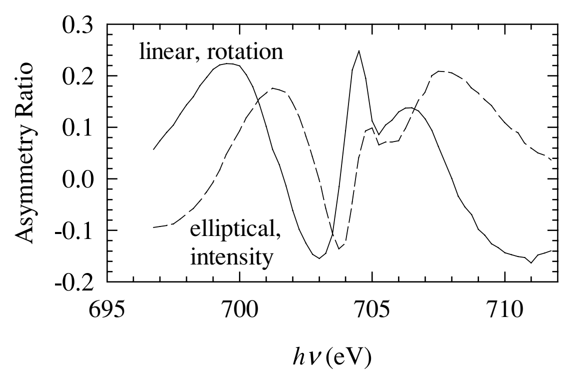

Figure 2. Measured asymmetry ratio spectra using linear Kerr rotation and near-circular Kerr intensity signals.

SPECTRAL ASYMMETRY SCANS

Spectral asymmetry ratios measured with the sample saturated (Fig. 2) using linear polarization ($P_L > 0.98$) and Kerr rotation and elliptical polarization ($P_C = 0.9$) and Kerr intensity are obtained as the difference over the sum of these respective signals. The slow oscillation in these signals results from thin-film interference effects, while the sharp features near 704 eV result from sharp resonant MO effects, as confirmed by model calculations using measured Fe MO constants.[2,3] These rotation and intensity spectra are proportional to the real and imaginary parts of the complex Kerr response, respectively, and can be seen to be related by a Kramers-Kronig transformation. Based on these spectra the energy of 704.7 eV, 2.3 eV below the Fe L_3 line, was chosen for further measurements below.

HYSTERESIS LOOPS

Photon detection facilitates hysteresis measurement, as shown in Fig. 3. The same signals were measured using linear and elliptical incident polarization as indicated. The “raw” Kerr rotation loops are those measured behind the linear polarizer, and are not symmetric for either incident polarization. The Kerr intensity loop measured with linear polarization is symmetric, while that measured with elliptical polarization is not. It is well known from visible MOKE that intensity signals using linear polarization result from changes in net transverse moment. The linear intensity signal is readily interpreted as showing a strong jump at low field when the top of the Fe layer reverses forming a twist structure having a net transverse moment. As the field increases the twist and transverse moment are pushed deeper into the Fe layer causing a decrease in signal, and at 0.8 T the hard layer and entire structure switch irreversibly with the intensity signal returning to the saturated value. While the elliptical XMOKE intensity loop has features that correspond to those in the linear loop, the elliptical loop is not symmetric precisely because only one helicity is present in the near-circular polarization, while both are present in the linear polarization. Interestingly, when the raw XMOKE rotation signal is normalized by the corresponding intensity signal, the normalized XMOKE rotation loop is symmetric and identical

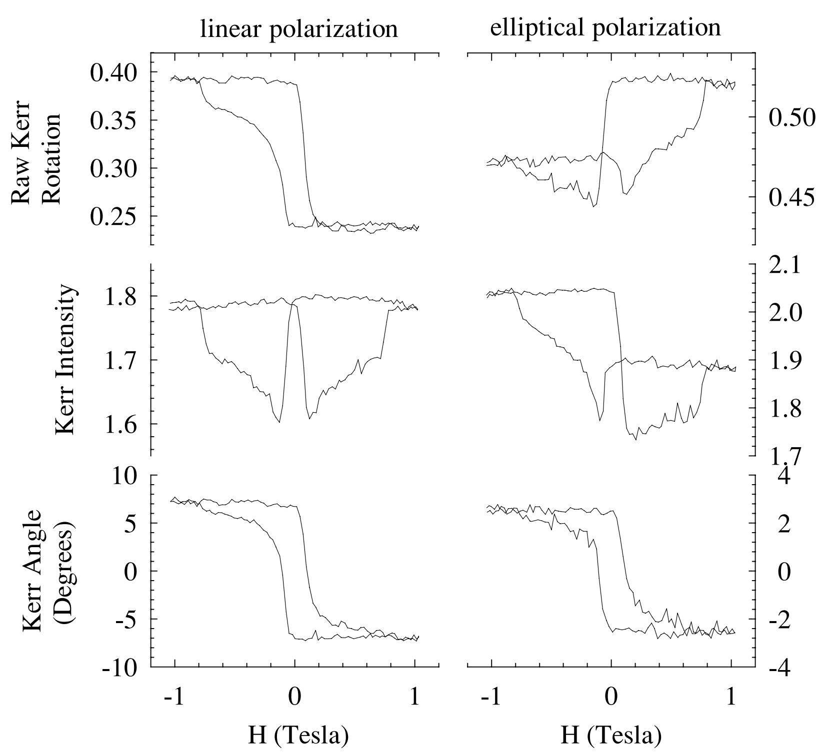

Figure 3. Hysteresis loops measured using linear and elliptical polarization are in the left and right column, respectively. In the top row are the raw Kerr rotation loops measured after the linear polarizer. In the middle row are Kerr intensity loops. In the bottom row are normalized Kerr rotation angle loops normalized first by dividing raw rotation by intensity signals, and then by putting the data on an absolute angle scale. Normalized Kerr rotation is primarily sensitive to longitudinal moments, while Kerr intensity using linear polarization is primarily sensitive to net transverse moments.

for both polarizations. These loops sense the longitudinal Fe moment, and show the abrupt change in longitudinal moment as the top reverses and a long tail as the bottom of the Fe layer remains pinned to the hard Sm-Co layer. It is clear that XMOKE loops using linear polarization are more readily interpreted in terms of longitudinal and transverse moments than are those using elliptical or circular polarization.

VARIABLE DEPTH SENSITIVITY

By tuning photon energy near the Fe L_3 edge the penetration depth can be varied considerably.[3] This was used to gain depth sensitivity to the reversal behavior of the Fe layer as shown in Fig. 3. This loop was measured just 1 eV above the L_3 line where penetration is severely limited, and shows very little Fe reversal at fields above 0.25 T. Thus this loop is sensitive to just the top of the Fe layer, while the loops measured below the L_3 line sense considerably more deeply into the Fe layer. Together the loops at different energies are a direct confirmation of the model whereby the top of the Fe layer reverses first while the bottom of the Fe layer remains pinned.

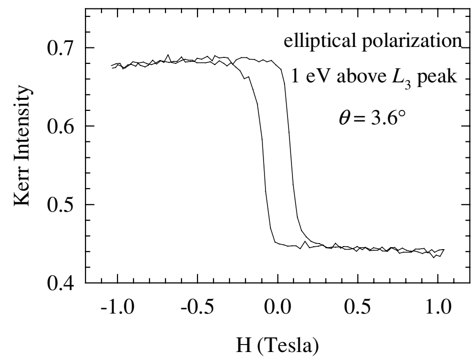

Figure 4. Elliptical XMOKE intensity loop measured at energy limiting penetration into Fe shows no clear indication of the buried twist structure.

CONCLUSIONS

Several conclusions are evident from data presented here and considered in more detail in ref. 2:

- As with the visible MOKE, transverse as well as longitudinal moments can be sensed using combined XMOKE intensity and rotation measurements. Exchange-spring samples exhibit both signals because of the spiral magnetization structure in the low-field reversible region.
- While both incident linear and near-circular polarization exhibit Kerr intensity and rotation signals in hysteresis loops, the signals using linear polarization show higher symmetry and hence are more simply interpreted than those using elliptical polarization. This is because linear polarization is a coherent superposition of each helicity circular polarization.
- Tuning energy near the strong Fe L_3 white line produces strong changes in penetration depth to provide for variable depth sensitivity.
- All of the XMOKE effects observed, including those resulting from interference of scattering from different layers, can be well modeled using existing magnetooptical formalisms and measured MO constants.

REFERENCES

[1] J. B. Kortright, D. D. Awschalom, J. Stöhr, S. D. Bader, Y. U. Idzerda, S. S. P. Parkin, I. K. Schuller, and H.-C. Siegmann, J. Magn. Magn. Mater. **207**, 7, (1999).

[2] J. B. Kortright, S.-K. Kim, E. E. Fullerton, J. S. Jiang, and S. D. Bader, Nucl. Instrum. And Methods A (in press).

[3] J. B. Kortright and S.-K. Kim, Phys. Rev. B

Work at LBNL and ANL was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Science Division, of the U.S. Department of Energy under Contract Nos. DE-AC03-76SF00098 and W-31-109-ENG-38, respectively.

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